KOPIO Task Force S/B: Outline

David E. Jaffe, BNL August 9, 2004

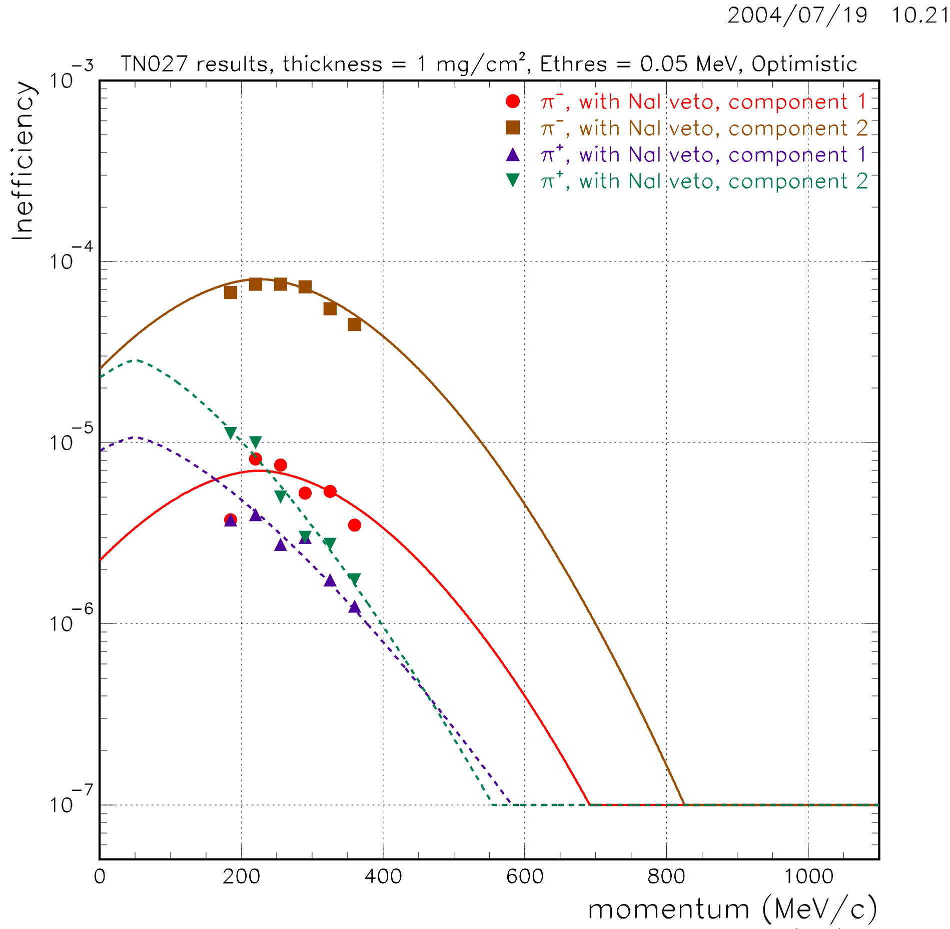
August 9, 2004

- Note on Beam Momentum, M.Zeller, 7 Aug 2004
- Note from D. Vavilov, 9 2004

1 Status of S/B studies, 9 Aug 2004

Work in Progress

1. Defining 1 KL/microbunch: Susan Kane is working with KOPIO GEANT MC to estimate signal reduction due to other KL. Report should be complete 16 Aug.
2. Effect of overlapping photon showers and $\mathrm{K}_\mathrm{L}^0 \to \pi^0\pi^0$ $\mathrm{K}_\mathrm{L}^0 \to \pi^0\pi^0\pi^0$ rates. Not yet begun.
3. Accidental losses. Marvin's technote on stopped muons. Andrei working on neutron halo files.
4. CV ineffy in FastMC revised following Andries van der Schaaf's recommendations. CV ineffy now takes into account additional detection effy due to PV. Pion ineffys based on TN027. See Figure 1. Still need to take dead material thickness into effect for $e^\pm, \mu^\pm$ ineffys.
5. CV timing studies, incomplete and preliminary.
Plot $t(\mathrm{trk}) - t(\mathrm{K}_\mathrm{L}^0) - |\vec{X}(\mathrm{trk}) - \vec{X}(\mathrm{K}_\mathrm{L}^0)|/\beta_{\max} c$ *vs* $M_\nu^2 \equiv (P(\mathrm{K}_\mathrm{L}^0) - P(\pi^0) - P(\pi)$. Assume $P(\pi) \approx M(\pi)$ and $\beta_{\max} = \beta$ assuming maximum allowed kinetic energy $T(\mathrm{K}_\mathrm{L}^0) - T(\pi^0) - M(\pi)$ (known to be incorrect for $e^\pm$ and decay-in-flight). Ignore impact position and time resolution. Assume CV in decay region is 140cm X 50cm (half-widths) box. Assume US and DS pipes lined with scintillator. Stop charged tracks at Z=1615cm as approximation to D4 magnet. Results in Figures 2 and 3
6. Simulated catcher ineffy as function of energy and detection algorithm provided by Hideki MORII. Parametrized and included in FastMC. See Figure 4
7. Figure 5 shows Andries's parametrization of the the PV ineffy in comparison to previous parametrization and E787 and preliminary E949 data.



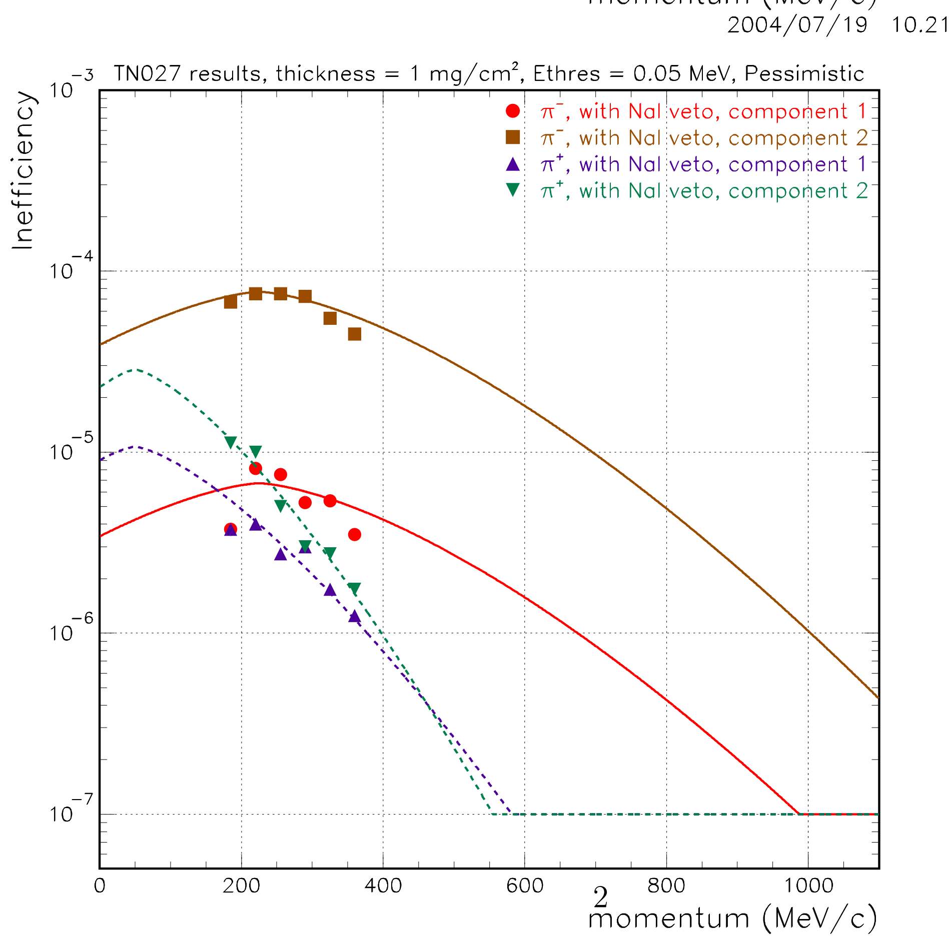


Figure 1: Upper(lower) charged pion ineffy with optimistic(pessimistic) assumptions. Component 1 is ineffy due to dead material. Component 2 is ineffy due to threshold.

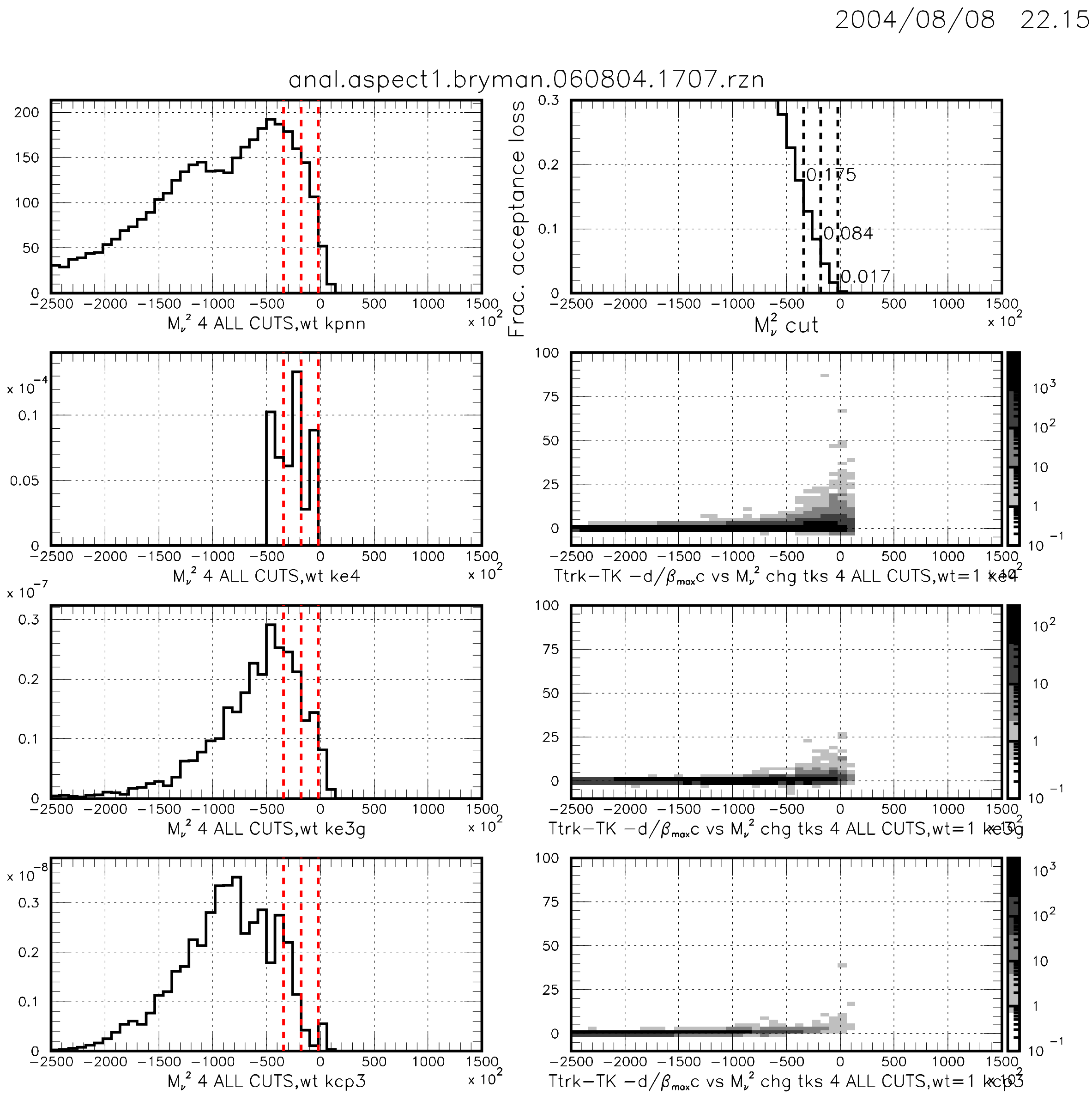


Figure 2: Left column: M_ν^2 for $\mathrm{K_L^0} \rightarrow \pi^0\nu\bar{\nu}$, $\mathrm{K_L^0} \rightarrow e^\pm\pi^\mp\pi^0\nu$ $\mathrm{K_L^0} \rightarrow e^\pm\pi^\mp\nu\gamma$ $\mathrm{K_L^0} \rightarrow \pi^0\pi^+\pi^-$. Dashed line show example cuts. Right column, top: signal acceptance loss for example cuts. Below: $t(\mathrm{trk}) - t(\mathrm{K_L^0}) - |\vec{X}(\mathrm{trk}) - \vec{X}(\mathrm{K_L^0})|/\beta_{\max}c$ *vs* $M_\nu^2 \equiv (P(\mathrm{K_L^0}) - P(\pi^0) - P(\pi)$ for backgrounds

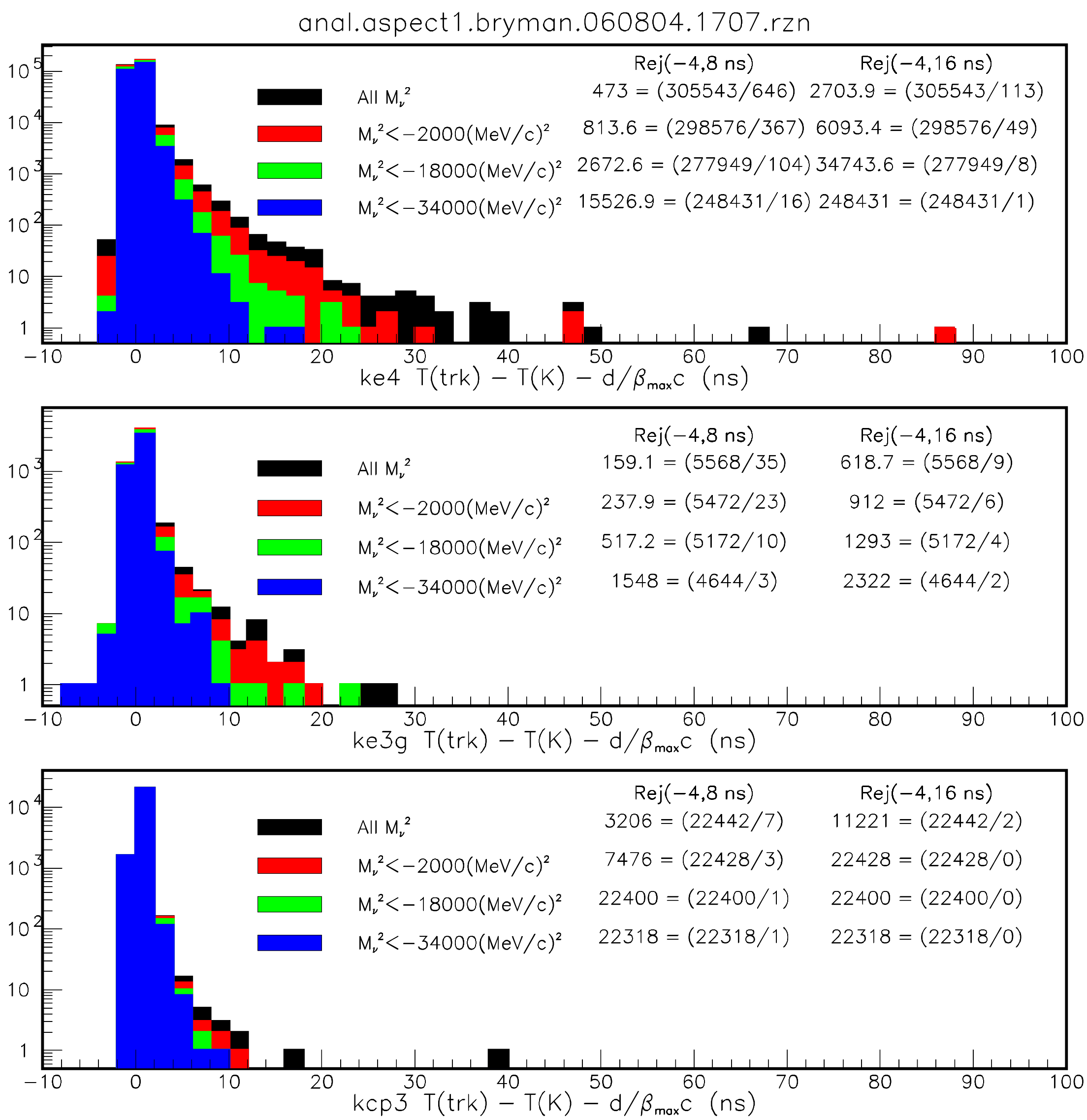


Figure 3: $t(\mathrm{trk}) - t(\mathrm{K_L^0}) - |\vec{X}(\mathrm{trk}) - \vec{X}(\mathrm{K_L^0})|/\beta_{\max}c$ (ns) for backgrounds after sample cuts. Rejection power of (-4,8)ns and (-4,16)ns veto gate is shown in figures.

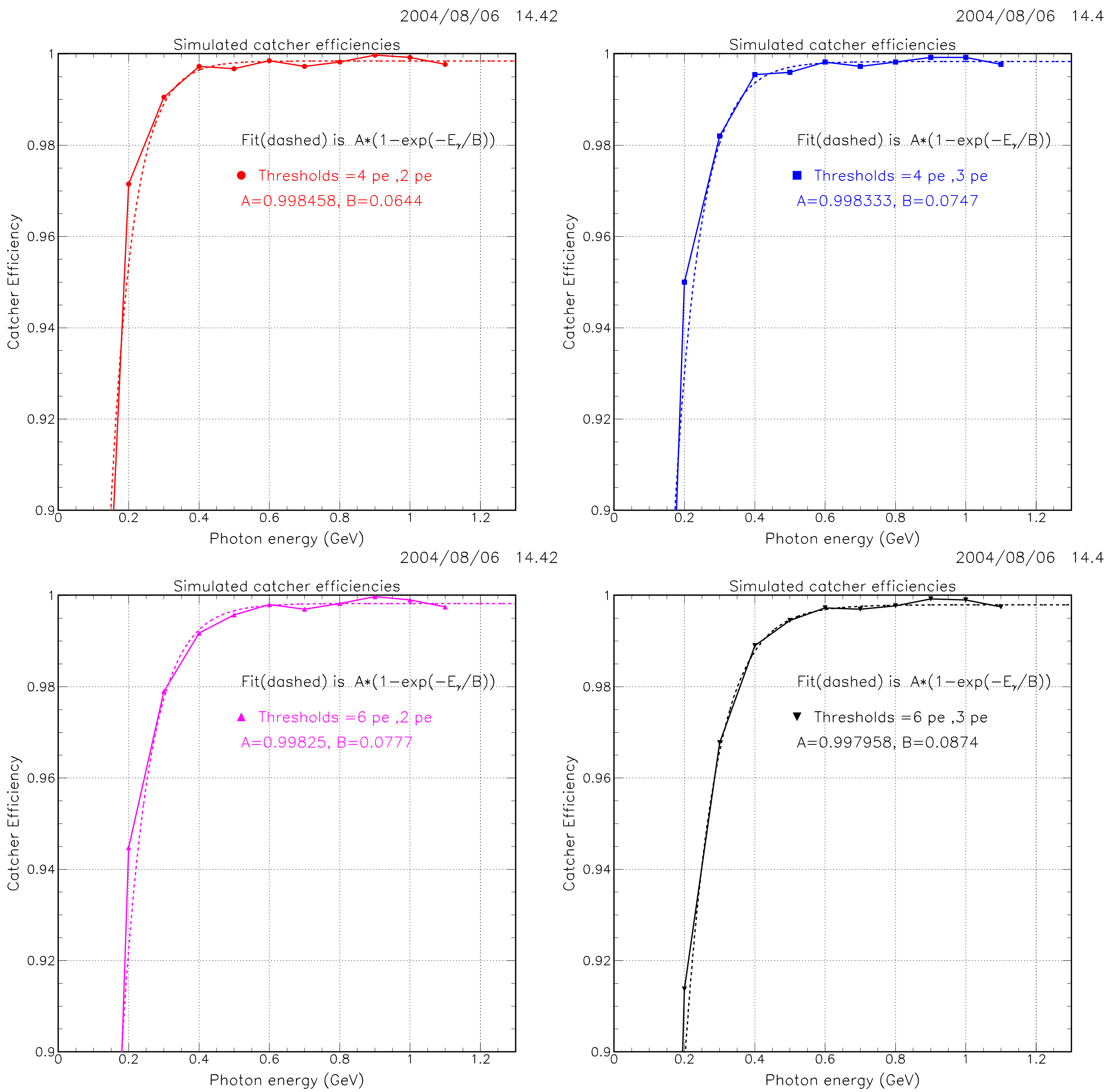


Figure 4: Simulated catcher effy vs photon energy in GeV and parametrization for different threshold requirements in single and backing catcher modules. Estimated false veto probabilities vary from 2.5% (top left) to 1.5% (lower right).

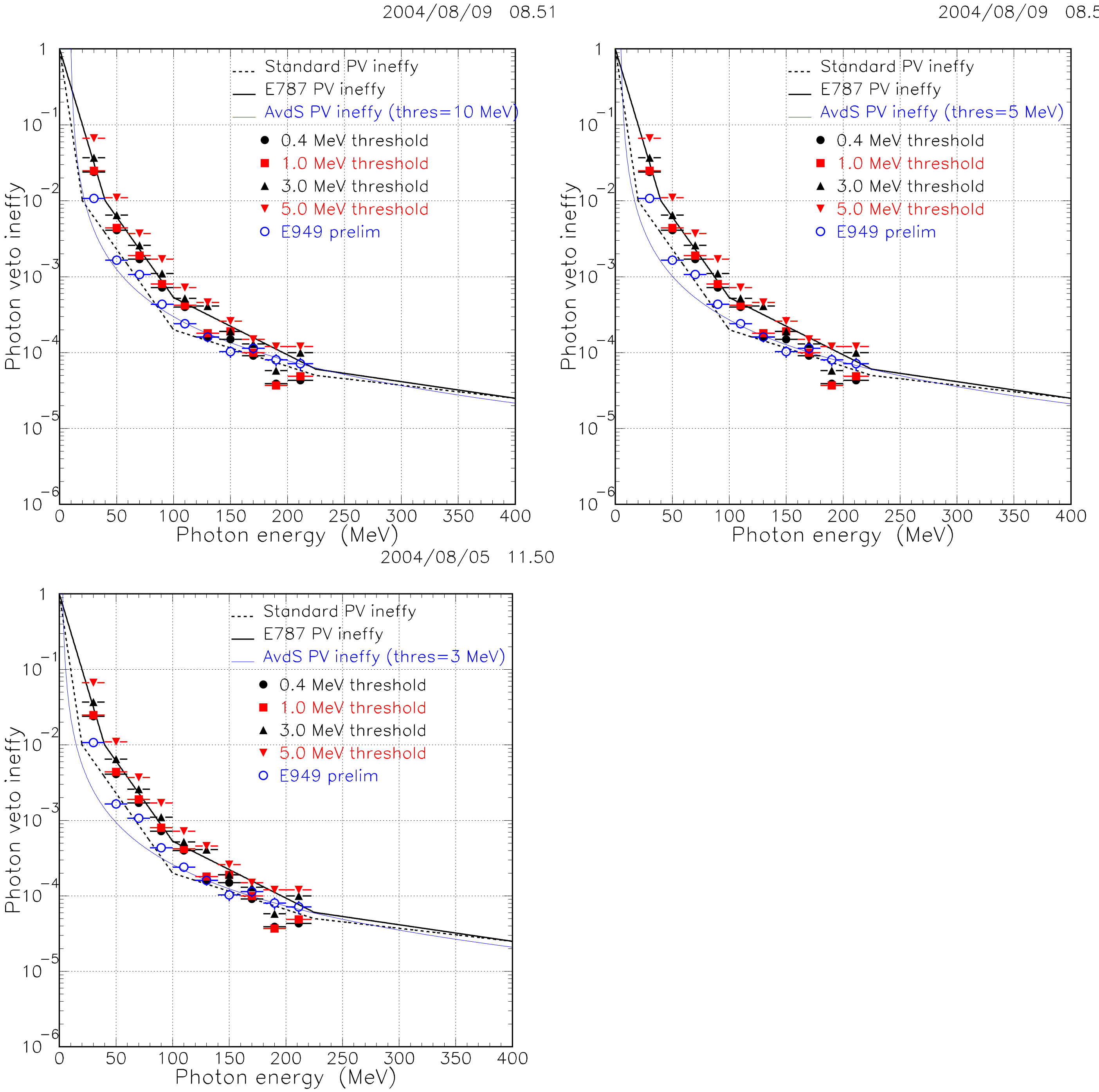


Figure 5: Andries's parametrization of the the PV ineffy in comparison to previous parametrization and E787 and preliminary E949 data.

8. Preliminary S/B results. After re-evaluating PV, CPV ineffys, Andries created cut based on contours in $(T^*(\pi^0))^2$ *vs* $\ln(E_{\rm miss})$. I supplemented them with

   (a) $180 < E^* < 290$ MeV, to remove regions of very low $K_L^0 \to \pi^0\nu\bar{\nu}$ acceptance and significant $K_L^0 \to \pi^0\pi^0$ acceptance,

   (b) $(|Y_{\rm miss}(PR)| > 5$ cm or $|\vec{P}_{\rm miss}| < 800$ MeV$/c)$, to remove events with a high energy (~ 1000 MeV) photon in the catcher and a low energy (~ 10 MeV) photon in the decay region, and

   (c) $(90 < |E^*_{\gamma 1} - E^*_{\gamma 2}| < 150$ MeV and $E_{\rm miss} < 350$ MeV), to remove events with a moderate energy (~ 50 MeV) photon in the US hole.

   Resulting rates (most efficient catcher algorithm):

```
  Using AvdS photon veto with threshold= 3.000 MeV and exponent= 1.800
  Use energy-dependent ineffy catcher model 1
Mode         Generated   Effy(wt)    N/N(Kpnn)   Nev(mode)   dNeV(mode)  Who
kpnn        0.1200E+07  0.3094E-02  1.000        117.9        0.4578      AvdS
*kpgg       0.3000E+06  0.1490E-09  0.2697E-02  0.3181       0.9577E-01  AvdS
*kp3        0.1200E+07  0.1140E-14  0.2595E-02  0.3061       0.2937E-01  AvdS
*kp2        0.1080E+08  0.5374E-10  0.5367      63.30        1.513       AvdS
*ke4        0.4000E+07  0.1209E-10  0.6748E-02  0.7959       0.2552      AvdS
*ke3g       0.2100E+07  0.1380E-12  0.5383E-02  0.6349       0.1687E-01  AvdS
*kcp3       0.4000E+07  0.1088E-13  0.1471E-01  1.735        0.6070E-01  AvdS
Key   N(Kpnn)/B  d(S/B)      Nev    dNeV
bkgd  1.758      0.4089E-01  67.09  1.539   AvdS
```

   Rates with least efficient catcher algorithm:

```
  Using AvdS photon veto with threshold= 3.000 MeV and exponent= 1.800
  Use energy-dependent ineffy catcher model 4
Mode         Generated   Effy(wt)    N/N(Kpnn)  Nev(mode)  dNeV(mode)  Who
*kp2        0.1080E+08  0.7772E-10  0.000      91.56      2.171       AvdS
```

- Status 19 July 2004
- A.Sher 19 July 2004: A note on the likelihoods for the Taskforce meeting
- Plans for S/B studies 28 June 2004
- Introduction

  Below I outline the issues for estimation of signal and background rates. We first need to accumulate and document the current information on each subject and then determine what studies need to be done and how to do them.

- Web Resources

  KOPIO Technotes
  Studies
  Meetings
  David Jaffe's page
  Andrei Poblaguev's page
  Akira Konaka's page
  Marvin Blecher's page
  Ermanno Imbergammo's page
  Andries van der Schaaf's page
  Hideki MORII's page
  Photonuclear Data Library
  IAEA Photonuclear Data Library

- Task force members

  Here's a list of members of this part of the task force. I've made tentative assignment of some items in the following list to individual members of the task force.

Initials	Name
DJ	David Jaffe
DV	Dima Vavilov
MB	Marvin Blecher
PR	Paolo Rumiero
AP	Andrei Poblaguev
MZ	Mike Zeller
AS	A.Sher
AvdS	Andries van der Schaaf
CS	Carol Scarlett
AK	Alexei Khotyanstev
LL	Laur Littenberg

- Initial detector definition I propose that the initial detector definition (geometry, veto inefficiencies, PR model) be taken v1_1 of the FastMC.
- K^0_L flux assumptions

1. Define “1 K_L^0 per microbunch” and acceptance loss **(DJ,MZ)**
2. production angle and aspect ratio **(LL)**
3. proton beam energy **(LL)**
4. K_L^0 production in target and spoiler by secondaries **(LL,AP)**
5. spoiler attenuation **(AP)**
6. other?

- List and estimate unaccounted signal losses

  1. < 100% of spill due to microbunching **(DJ)**
  2. trigger efficiency **(GR)**
  3. reconstruction efficiency **(MB)**
  4. photon absorption/interactions**(DJ)**
  5. dead time **(GR)**
  6. losses due to accidentals**(MZ)**
  7. other?

- Acceptance components

  I propose that **DJ, DV, CS, PR and AS** use the FastMC to provide answers for the items in this section. I **(DJ)** will collect the current documentation.

  Signal and background acceptance for each possible pair of reconstructed photons. See Table 1. There are up to 66 possible pairs given the 11 classes in the Table. Study of pairs lacking any PR information can be postponed or neglected as they probably have very poor S/B.

- Resolution and tails

  1. Resolution and tails on X_K, Y_K without the Y-beam envelope constraint. Needed to determine how close CV can be placed to beam.
  2. Contribution to resolution/tails on $X_K, Y_K, Z_K, T_K, E^*_\pi, E^*_\gamma, M_{\gamma\gamma}$ due to
     (a) Assume photon hit resolution
     (b) Type of photon pair (Table 1)
     (c) Kinematics
     (d) Photon scattering and absorption in material
     (e) Photon impact position, angle and energy

- Optimization of cuts There are many possible reconstructable photon pair classes. Ideally one would like to have optimized cuts for each class (and each detector configuration). Is it possible to improve and/or automate the optimization of cuts?

Number	Class
1	PR face/CAL
2	PR hole/CAL
3	PR side/CAL
4	PR/PR
5	PR/OV
6	PR/OV&CAL
7	CAL/CAL
8	BV/BV
9	BV/BV&OV
10	OV/OV
11	OV/OV&CAL

Table 1: Reconstruction photon classes. Nomenclature: Conversion point/energy deposit. "PR face" denotes photons that pass through the front face of the PR. "PR hole" denotes photons that pass through the beam hole and strike the PR. "PR side" denotes photons that impact the PR on each side ($\pm X$) of the beam hole.

- Background

  The five main items listed below are all inter-related. For example, we need to assess the background rate from each source and "timing" taking into account the appropriate background suppression methods.

  1. Background "timing"
     - (a) From same bunch
     - (b) From previous bunch ("wrap-around")
     - (c) From interbunch
     - (d) Due to bunch width/bunch shape
  2. Background sources
     For 15 June 04 meeting, we want to have a targeted discussion of each individual background source which clearly describes how the suppression works and what may be the issues. The responsible individual is indicated below. For each mode, the individual should give the background mechanism(s) and the suppression methods (PV, CV, kinematics, branching fraction, production rate, etc.) taking into account the elements in this section (resolution, timing, etc.).
     - (a) K^0_L (Roughly in order of importance)
       - i. $\mathrm{K}^0_\mathrm{L} \to \pi^0\pi^0$ **(DV,PR)** (Section 3.1)
       - ii. $\mathrm{K}^0_\mathrm{L} \to \pi^0\pi^+\pi^-$ **(MZ)**
       - iii. $\mathrm{K}^0_\mathrm{L} \to e^\pm\pi^\mp\nu\gamma$ **(MB)** (Section 3.2)
       - iv. $\mathrm{K}^0_\mathrm{L} \to e^\pm\pi^\mp\pi^0\nu$ **(AS)**

v. $\mathrm{K_L^0} \to \pi^0\pi^0\pi^0$ **(DJ)** (Section 3.6)

vi. $\mathrm{K_L^0} \to \pi^0\gamma\gamma$ **(DJ)** (Section 3.6)

vii. $\mathrm{K_L^0} \to \gamma\gamma$ **(DJ)** (Section 3.6)

viii. $\mathrm{K_L^0} \to e^\pm\pi^\mp\nu$ **(LL)** (Section 3.3)

ix. $\mathrm{K_L^0} \to \gamma e^+e^-$ **(LL)** (Section 3.5)

x. $\mathrm{K_L^0} \to \pi^+\pi^-$ **(LL)** (Section 3.4)

(b) Neutrons **(AP)**

(c) Hyperons **(CS)**

(d) Charged kaons in beam and from $\mathrm{K_L^0}$ CEX in collimators **(CS)**

(e) Charged pions from $\mathrm{K_L^0}$ decay **(CS)**

(f) Multiple $\mathrm{K_L^0}$ (2 $\mathrm{K_L^0}$ decays reconstucted as a single candidate) **(CS)**

(g) Other?

3. Background suppression issues for neutral modes ($2\pi^0$, $3\pi^0$, $\gamma\gamma$, $\pi^0\gamma\gamma$, others)

   (a) Overlapping photons**(MZ)**

   i. As signal candidate

   ii. Effect on photon veto inefficiency

   (b) Photon veto assumptions **(AvdS)** Overview

   i. Hermiticity

   ii. Energy-dependence of timing

   iii. Catcher inefficiency

   iv. Guard counter inefficiency

   v. Losses due to dead material

   vi. E787 Single Photon Inefficiency vs pi0 Inefficiency and comment on Burtovoy's TN088

4. Background suppression issues for charged modes ($\pi\pi\pi^0$, $\pi e\nu$, $\pi e\nu\gamma$, $\pi\pi^0 e\nu$, γe^+e^-, others?)

   (a) Charged veto assumptions **(AvdS)**
   Overview

   i. Hermiticity

   ii. Energy-dependence of timing

   iii. Losses due to dead material

5. Neutron background issues

   (a) Y_K and Z_K resolution and tails

   (b) Timing

   (c) Vacuum requirements

   (d) Beam and halo spectra: need flux = f(px,py,pz,x,y,z) **(AP)**

- Accidentals: Source, location, spectrum and rates.

1. $\mathrm{K^0_L}$ **(LL,MZ)**
2. Neutrons **(AP)**
3. Prompt photons from target/spoiler/collimators **?**
4. Stopped muons **(MB)**
5. other?

1. Effects on veto efficiencies
   (a) Veto blindness
   (b) False vetos
2. False signal candidates

- Anything else?

2 Summary of 15 June 04 meeting

General:

1. FastMC PV function will be updated info measurements and MC for $E_\gamma > 150$ MeV from GR's group.
2. Should use "Bryman" PR model in FastMC
3. Need to get accidentals rates in PR/CAL for FastMC estimates.

To do:

1. $\mathrm{K^0_L} \to \pi^0\pi^0$ **DV** : More quantitative investigation of contributions due to
   (a) overlapping photon
   (b) interbunch
   (c) 'bunch widths'
2. $\mathrm{K^0_L} \to \pi^0\pi^+\pi^-$ **(MZ)**
3. $\mathrm{K^0_L} \to e^\pm\pi^\mp\nu\gamma$ **MB and DJ** will work to resolve differences between FastMC and GEANT calculation of $e^+\pi^-$ component of background. If rate is significant, then need to review CV timing.
4. $\mathrm{K^0_L} \to e^\pm\pi^\mp\pi^0\nu$ **(AvdS)**
5. $\mathrm{K^0_L} \to \pi^0\pi^0\pi^0$ **(DJ)**
   (a) More detailed study of effect of PV energy dependence
   (b) Overlapping photons

6. $K^0_L \to \gamma\gamma$: Need rate from $K^0_L \to \gamma\gamma$ combined with accidental.
7. $K^0_L \to \pi^0\gamma\gamma$: Rate negligible if $K^0_L \to \pi^0\pi^0$ rate is reasonable.
8. $K^0_L \to e^\pm\pi^\mp\nu$: Need confirmation of $e^+\pi^-$ component of background.
9. $K^0_L \to \gamma e^+e^-$: Rate negligible
10. $K^0_L \to \pi^+\pi^-$: Rate negligible

3 Reports

3.1 $K^0_L \to \pi^0\pi^0$ background

pdf

3.2 $K^0_L \to e^\pm\pi^\mp\nu\gamma$ background

```
From blecherm@enterprise.phys.vt.edu Tue Jun 15 08:39:53 2004
Date: Mon, 14 Jun 2004 20:51:22 -0400 (EDT)
From: Marvin Blecher <blecherm@enterprise.phys.vt.edu>
To: dave jaffe <djaffe@bnl.gov>

The backgrounds K_L -> e(+-) pi(-+) nu gamma:
BR = 3.5e-03
Sig BR = 3e-11

1) e(+) final state

(a) e(+) converts in flight without detection 2.5e-04 (LL)
          into a very hard gamma and a missed very soft gamma
    pi(-) is missed 3e-04 (LL)
    hard and original gamma simulate a pair
    with good Mgg and vertex. < 5e-03 x signal acc
    B/S < 0.04

(b) miss e(+) and annihilation gammas (<2.5e-04)
    pi(-)p-> pi(0)n before detection   (3e-04)
    original gamma missed             (6e-04)
    B/S = 0.005

(c) miss e(+) and annihilation gammas (<2.5e-04)
    pi(-)p -> gamma n before detection (3e-06)
    this gamma pairs with original gamma
    with good M and vertex  (< 5e-03 sig acc)
    B/S = 0.004
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2) e(-) final state

a) cannot occur

```
b) and c) occur through pi(+)n -> pi(0)p
                               -> g p
 Here there is a chance of vetoing on the p
 and missing e(-) harder than missing e(+)so S/B even lower.
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d) e- makes a hard brem before detection then like a)
The brem and miss possibility is less than the annihilation
and miss probability so B/S < 0.04.

3.3 $\mathrm{K}^0_{\mathrm{L}} \to e^{\pm}\pi^{\mp}\nu$ background

From littenbe@bnl.gov Tue Jun 15 08:51:23 2004
Date: Mon, 14 Jun 2004 23:05:07 -0400
From: Laurence Littenberg <littenbe@bnl.gov>
To: David E Jaffe <djaffe@bnl.gov>
Cc: archive <litt@sun2.bnl.gov>
Subject: Ke3

Here we are starting from a 40% branching ratio, so have to go a long way down to be safe. It seems to me there are at least four paths by which this decay can look like a signal:

1. The e- evades the CPV (6.5 x 10^-5) and the pi+ charge-exchanges early in the CPV (2 x 10^-6 x ~1/3). This gives an effective BR of ~ 2 x 10^-11 before we begin to ask whether the pi0 mis-reconstructs into the beam. Seems quite safe.

2. The e+ annihilates in the CPV (say 5 x 10^-3), both photons are missed (5 x 10^-5, 0.1), and the pi+ charge-exchanges in the CPV (2 x 10^-4 x ~ 1/3). This gives a partial BR of ~7 x 10^-13 before pi0 mis-reconstruction, passing kinematic cuts, etc. Seems safe.

3. The pi+ and the e- both evade the CPV and contrive to put photon-like showers into the front detectors. For conservatism assume that every time the e- disappears, it gives essentially all its energy to a photon (6.5 x 10^-5). When the pi+ disappears (2 x 10^-6), for conservatism use the same 1/3 as we use for charge exchange. This yields an effective BR of 1.7 x 10^-11 before asking how often the two "photons" reconstruct to a pi0 and passes our kinematic cuts. One should note that there will also

be some degree of timing suppression of any path that involves a slow pion since it takes longer than a photon to reach the counter in which it converts to a photon or pi0. In any case this path seems reasonably safe.

4. The pi- and the e+ both evade the CPV and contrive to put photon-like showers into the front detectors. The e+ annihilates (5 x 10^-3) and the low energy photon is missed (0.1), the pi- is missed in the CPV (2 x 10^-4), and again for conservatism we take 1/3 as the probability it produces a single gamma. At this point the effective BR is still 1.3 x 10^-8, so that further close examination of the problem will be needed.

3.4 $\mathrm{K}_\mathrm{L}^0 \to \pi^+\pi^-$ background

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From littenbe@bnl.gov Fri Jun 11 09:11:12 2004
Date: Thu, 10 Jun 2004 23:29:49 -0400
From: littenbe@bnl.gov
To: David E Jaffe <djaffe@bnlku5.phy.bnl.gov>
Cc: archive <litt@sun2.bnl.gov>
Subject: Re: Update for S/B tasks

David,

I'm not entirely sure what you want, but let me try out the third
of the reactions you assigned me, i.e K_L => p+,pi-.  This one doesn't
seem too dangerous at first sight, but it may not be completely
negligible.  The BR is about 2 x 10^-3.  The reaction I guess I'd worry
about is the pi- disappearing before registering in a CPV and the pi+
charge-exchanging.  If we take as the probabilty of pi- disappearance
3 x 10^-4.  Therefore, at this point the effective BR is 6 x 10^-7.
The charge exchange can either take place off a residual gas molecule
in the beam, where the probability of reconstruction is highest, or
off a more substantial piece of material out of the beam, which is much
more likely, but where the probability of acceptable reconstruction is
much less.
Let me take these up one at a time:

1. Interaction in the beam.
The density in the beam is 10^-7 * 1/760 * density of air at STP
                                  = 1.316 x 10^-10 * 1.29 g/l
                                  = 1.7 x 10^-10 g/l = 1.7 x 10^-13 g/cm^3
Say on the average the pi+ has 200cm of possible path, then it encounters
3.4 x 10^-11 g/cm^2 of air.  To be very conservative take the asymptotic
interaction length of air, 90g/cm^2 as the interaction length for charge
exchange (the low energy total cross section is higher, but the CE
cross section is not the whole thing).  Then the probability of CE is
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3.8 x 10^-13. You can forget this path.

2. Interaction in some material off the beam.
If it hits a CPV, it's got to pay a price of say 3 x 10^-5 for not firing it, this takes the effective BR to 1.8 x 10^-11. Given the probability of CE, reconstruction, looking like a pi0, yet seeming to come from the beam, etc., it seems like one can forget this path, too. But how about if it hits the 50 micron Be window we're talking about putting at the entrance of the DS beampipe? This has about 0.01g, and say the CE cross-section is ~130mb (=4 x this CE cross section off d at 300 MeV/c), then get a probability of 8.8 x 10^-5. Then the equivalent BR at this point is 5.3 x 10^-11. One then has to multiply by the probability of the resulting pi0 reconstructing some 50cm upstream from its actual origin, passing our cuts, etc. It seems safe.

Finally, one could worry about the pi+ and the pi- separately evading our CPV's but putting a signal into the detector that looks like photons. The partial BR for the first part of this, i.e. evading the CPVs, is 2x10^-3 * 3x10^-4 * 3x10^-5 = 1.2x10^-11. Then one has the probability of each particle producing something that can be taken for a photon, the photons reconstructing as a pi0, etc. This also seems safe.

Laur

On Thu, 10 Jun 2004, David E Jaffe wrote:

>
> Hi folks,
>
> I've updated http://www.phy.bnl.gov/~djaffe/KOPIO/TaskForce/outline/
> based on some discussion with other task force members.
>
> The following people have been assigned a background source
> (see the section "Background sources" in
> http://www.phy.bnl.gov/~djaffe/KOPIO/TaskForce/outline/)
> for the 15 June meeting: DV, DJ, MB, MZ, AvdS, LL, CS, AP
>
> Please let me know if you will be unable to contribute.
> Thanks.
>
>
> Best regards,

```
> David
>
> David E. Jaffe - Physics Dept - BNL, Bldg 510E - Upton,NY 11973-5000 USA
> tel: 631.344.5518  fax: 631.344.4741   djaffe@bnl.gov djaffe@eudoramail.com
>
>
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3.5 $\mathrm{K_L^0} \to \gamma e^+ e^-$ background

```
From littenbe@bnl.gov Mon Jun 14 11:06:39 2004
Date: Mon, 14 Jun 2004 10:07:40 -0400
From: littenbe@bnl.gov
To: David E Jaffe <djaffe@bnl.gov>
Cc: archive <litt@sun2.bnl.gov>
Subject: e,e,gamma



B(K_L -> e,e,gamma)=10^-5.  At first sight, it doesn't seem too
worrysome since the probability of missing both the e+ and e- is rather
small (~.05/E(MeV) & 6.5 x 10^-5), and even after that you'd need to have
a gamma that points back to the vertex and reconstructs with the primary
gamma to make an apparent pi0, and pass all the kinematic cuts.  However
there are some potentially nasty correlations possible, so this mode needs
at least a cursory examination.  Let's at least look at the case wherein
the e- is very soft and the e+ annihilates.  Say the pair has energy 200
MeV and the e- will be lost if it has energy below 0.075 MeV/c.  The
probability of this split is roughly 0.075/200 = 3.75 x 10^-4, which is 6
times higher than assumed above.  The probability of the e+ annihilating
is 2.5 x 10^-4, and one will tend to miss the low energy gamma.  This
gives an overall effective BR ~10^-12, before taking into account the
reconstruction and kinematics and seems OK. What I worry about is the fact
that the e+ and e- are very often emitted close together so that certain
kinds of inefficiency (e.g. veto blindness or cracks) might be correlated
between the two, reducing the rejection powers mentioned above by quite a
bit.

Laur
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3.6 $\mathrm{K_L^0} \to \pi^0\pi^0\pi^0$ $\mathrm{K_L^0} \to \pi^0\gamma\gamma$ and $\mathrm{K_L^0} \to \gamma\gamma$ backgrounds

This section by D.Jaffe, 14 June 2004.

As a benchmark take the branching fraction ($\mathcal{B}$) times acceptance ($\mathcal{A}$) for signal $\approx (3 \times 10^{-11}) \times (1\%) = 3 \times 10^{-13}$ reduced by an additional factor of 10 for comparison with backgrounds due to $K^0_L \to \pi^0\pi^0\pi^0$ $K^0_L \to \pi^0\gamma\gamma$ and $K^0_L \to \gamma\gamma$.

1. $K^0_L \to \pi^0\pi^0\pi^0$ background

   $\mathcal{B} = 21.1 \pm 0.3\%$.

   Main suppression method is photon veto. Roughly speaking, $\mathcal{B} \times \bar{\epsilon}^4_{\mathrm{PV}} < 3 \times 10^{-14}$ or an average $\bar{\epsilon}_{\mathrm{PV}} < 6 \times 10^{-4}$ is required. At first glance that appears to be achieveable, however, because of the high multiplicity, the mean photon energy is about 160 MeV/c [1]. With the standard $\bar{\epsilon}_{\mathrm{PV}}$, $\bar{\epsilon}_{\mathrm{PV}} \approx 1.8 \times 10^{-3}$ averaged over photon energies for kinematically acceptable candidates was determined in Table 2 of [1]. This implies a (surprisingly large?) kinematic suppression of $\sim 3^4 \times 3 = 240$ where the additional factor of three arises from the fact that the calculated rate in [1] is approximately 1/30 of the signal rate as opposed to $1/10^{\mathrm{th}}$ of the benchmark 3×10^{-14}.

   TN-083 [1] has already shown that the $K^0_L \to \pi^0\pi^0\pi^0$ becomes overwhelming if the low energy PV inefficiency is too high.

2. $K^0_L \to \pi^0\gamma\gamma$ background

   $\mathcal{B} = (1.7 \pm 0.1) \times 10^{-6}$.

   The π^0 has the same phase space as $K^0_L \to \pi^0\nu\bar{\nu}$ although the dynamics are different so once again the main suppression method is the photon veto. $\bar{\epsilon}_{\mathrm{PV}} < 1.3 \times 10^{-4}$ gives an $\mathcal{B} \times \mathcal{A} < 3 \times 10^{-14}$. This is a lower inefficiency per photon than required for $K^0_L \to \pi^0\pi^0\pi^0$ but note that the average photon energy is higher. It would probably be wise to re-evaluate this background for different assumptions about the energy dependence of the PV.

3. $K^0_L \to \gamma\gamma$ background

   $\mathcal{B} = (5.96 \pm 0.50) \times 10^{-4}$.

   Kinematic suppression dominates since $M_{\gamma\gamma} >> M(\pi^0)$. There would also be very little missing energy and the energy in the K^0_L rest frame is at the kinematic limit. All previous FastMC calculations that I know about have verified these assumptions; however, the possibility that a photon is missed and the remaining photon is coupled with an accidental has not been considered.

   Assuming the probability to miss a photon is $\sim 1 \times 10^{-4}$ implies that a suppression of $\sim 2 \times 10^6$ is needed from kinematics and the accidental rate. Here is a specific case of a scenario that would produce background: γ_1 hits PR far from beam hole and provides the angular information needed to determine the K^0_L vertex, γ_2 hits catcher and is undetected, γ_{acc} is near beam hole, provides mainly energy and timing information, and gives acceptable kinematics. The current cuts that suppress photon pairs with asymmetric energy, targetted mainly at odd $K^0_L \to \pi^0\pi^0$ background, would probably be effective. To calculate this rate we need the accidental rate and energy spectrum in the PR/CAL, initially, and ultimately the accidental rate and spectrum in each detector that might be considered as a 'signal' photon detector (BV, OV, etc.).

References

[1] D.E.Jaffe, *FastMC comparison of standard and E787 photon veto inefficiency*, TN083, 15 April 2004.